



# 'Alarm' and 'Danger' Criteria in Foot Temperature to Prevent Heat Stroke in Workers Wearing Personal Protective Clothing

Joo-Young LEE<sup>1,2\*</sup>, Kouhei NAKAO<sup>1</sup>, Ilham BAKRI<sup>1,3</sup> Yutaka TOCHIHARA<sup>1</sup>

<sup>1</sup> Department of Human Science, Kyushu University, Japan; <sup>2</sup>Japan Society for Promotion of Science (JSPS); <sup>3</sup> Engineering Department, Hasanuddin University, Indonesia

## Backgrounds



Vinyl suit  
Japan Atomic Energy Agency

Workers wearing personal protective equipment (PPE) in hot environments often encounter severe heat stress. To prevent heat stroke, numerous criteria have been put forth as guidelines: ISO 7243 (Wet Bulb Globe Temperature Index, WBGT) set "Safe" WBGTs.: ISO 7933 (2004) provides physiological criteria for determining the maximum allowable exposure. However, the real-time monitoring of physiological variables during working is relatively less feasible for workers equipped with full protective clothing. To facilitate the assessment of the thermal state of PPE-workers, the development of **non-Invasive and simpler measurements** is needed as a valid criterion.

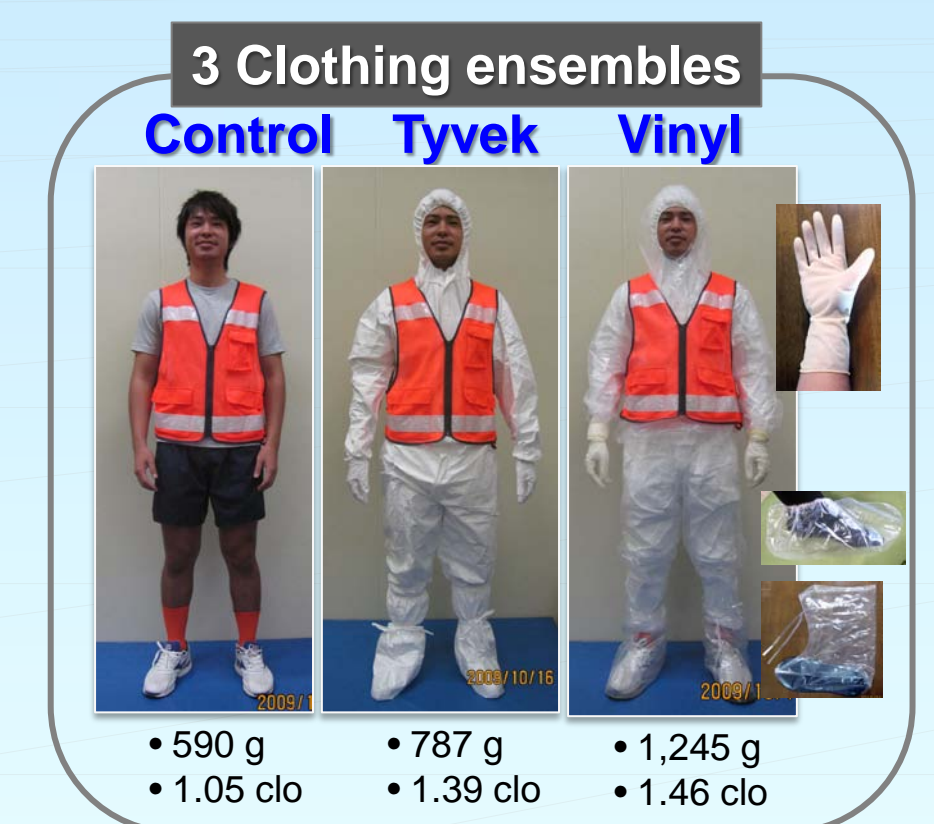
■ **Purpose:** Investigation of the feasibility of foot temperature as a non-invasive and simpler criterion to assess the heat strain of PPE-workers.

## Methods

■ A total of **20** experimental conditions through **2** series of studies with 16 subjects (8+8 subjects)

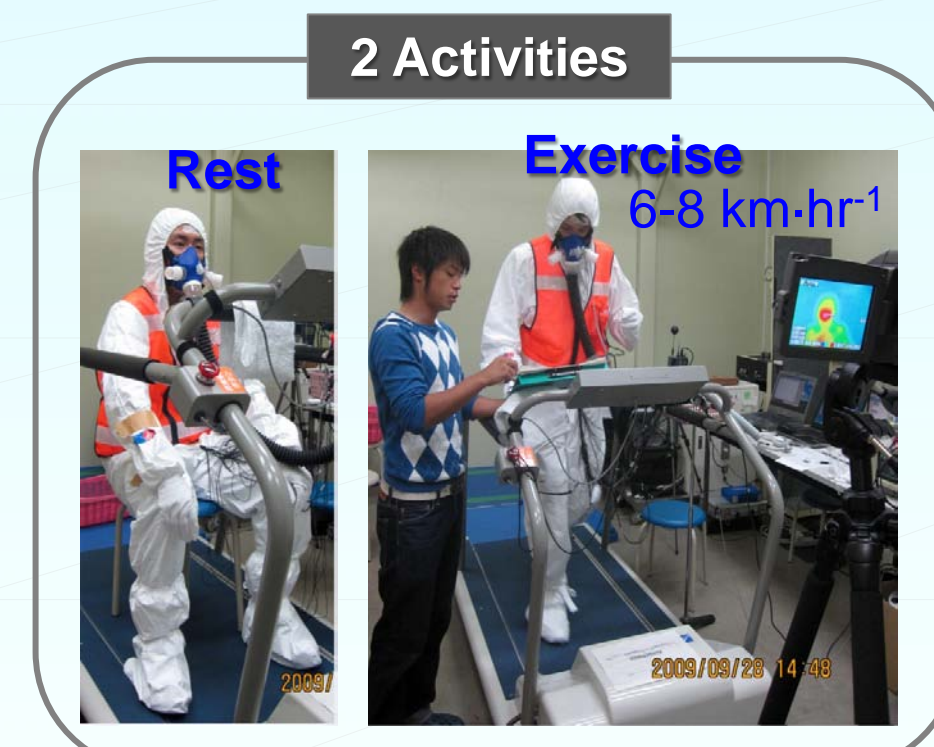
○ **[Series 1] 12 conditions**  
= three clothing ensembles × two air temp. (25 & 32°C, 50%RH) × two activities

○ **[Series 2] 8 conditions**  
= Four types of firefighter's PPE × two air temp. (22 & 32°C, 50%RH) × one activity

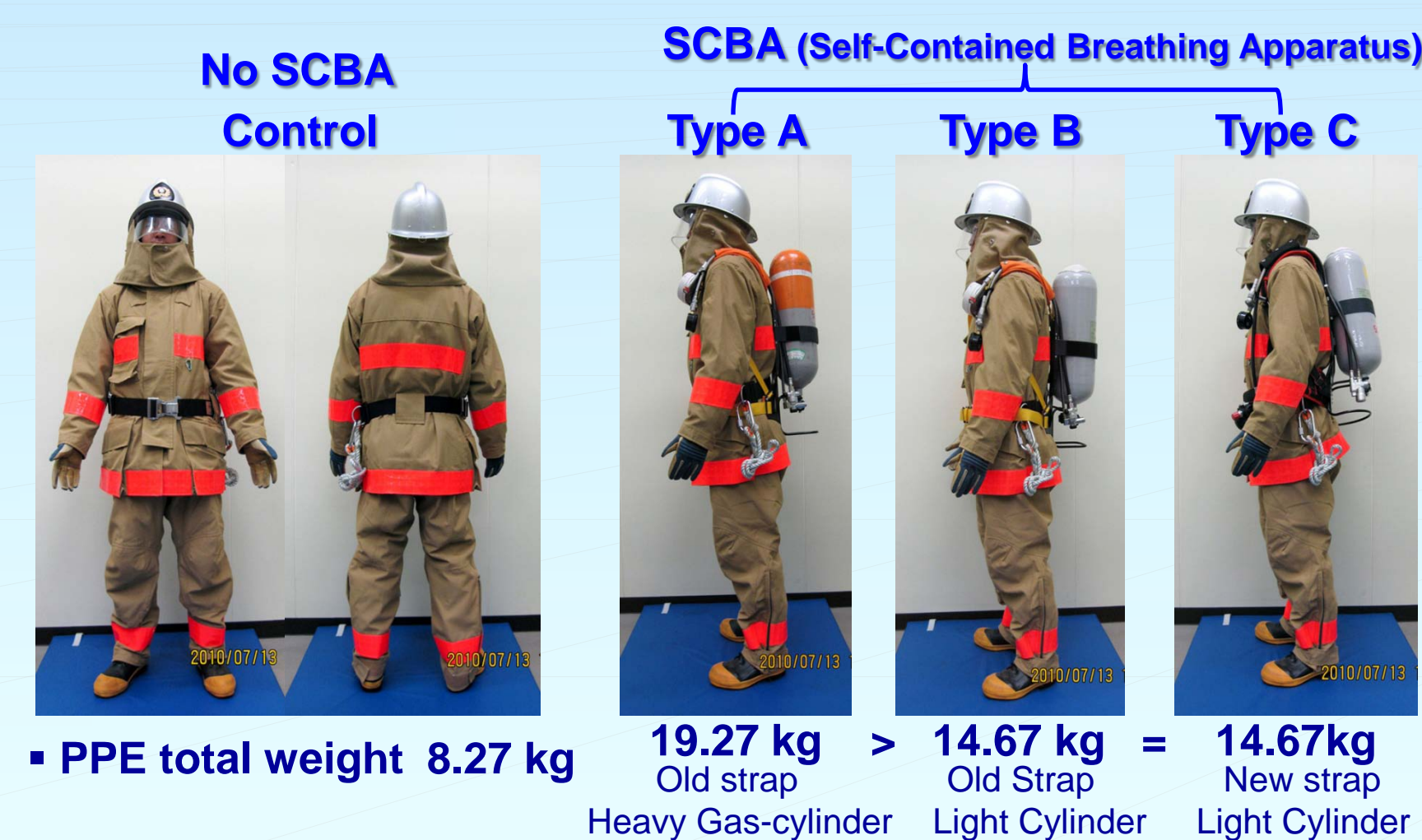


3 Clothing ensembles  
Control Tyvek Vinyl

• 590 g  
• 1.05 clo  
• 787 g  
• 1.39 clo  
• 1,245 g  
• 1.46 clo



2 Activities  
Rest Exercise  
6-8 km-hr<sup>-1</sup>

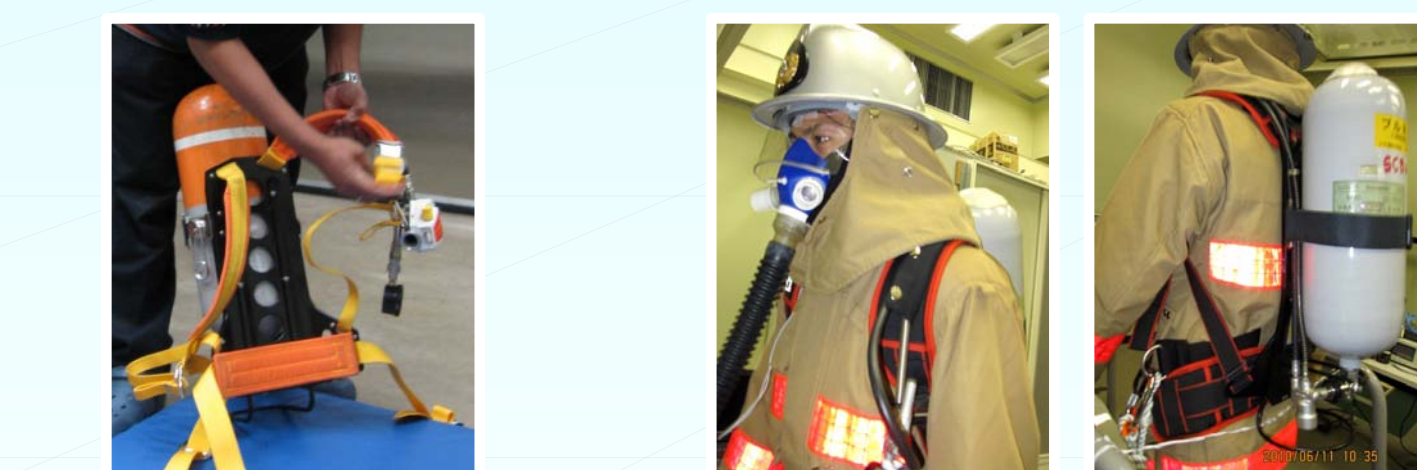


No SCBA  
Control

SCBA (Self-Contained Breathing Apparatus)  
Type A Type B Type C

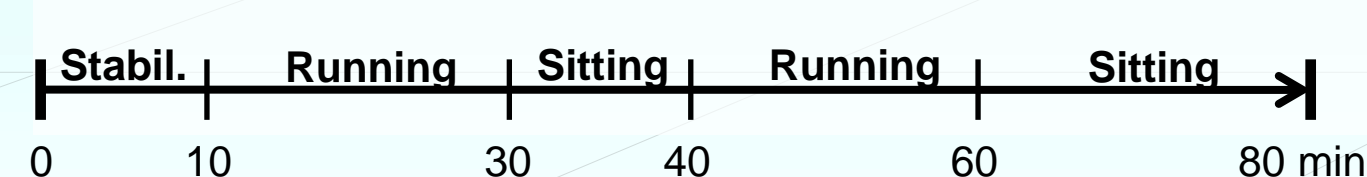
• PPE total weight 8.27 kg

19.27 kg > 14.67 kg = 14.67 kg  
Old strap Heavy Gas-cylinder Old Strap Light Cylinder New strap Light Cylinder



Old straps

Improved straps



## Measurements

: Skin temp. on 11 sites (2s), Rectal temp:  $T_{re}$  (2s), Heart rate (2s), Total sweat rate, Thermal sensation (10min), Thermal comfort (10min).

## Calculation

: Physiological Strain Index (PSI)

## Results

- $T_{foot}$  reached  $T_{re}$  for the cases where Tyvek coverall was worn at 32°C.
- For Vinyl condition at 32°C,  $T_{foot}$  finally exceeded  $T_{re}$  during exercise.
- In most cases, mean  $T_{sk}$  was lower than  $T_{foot}$ .

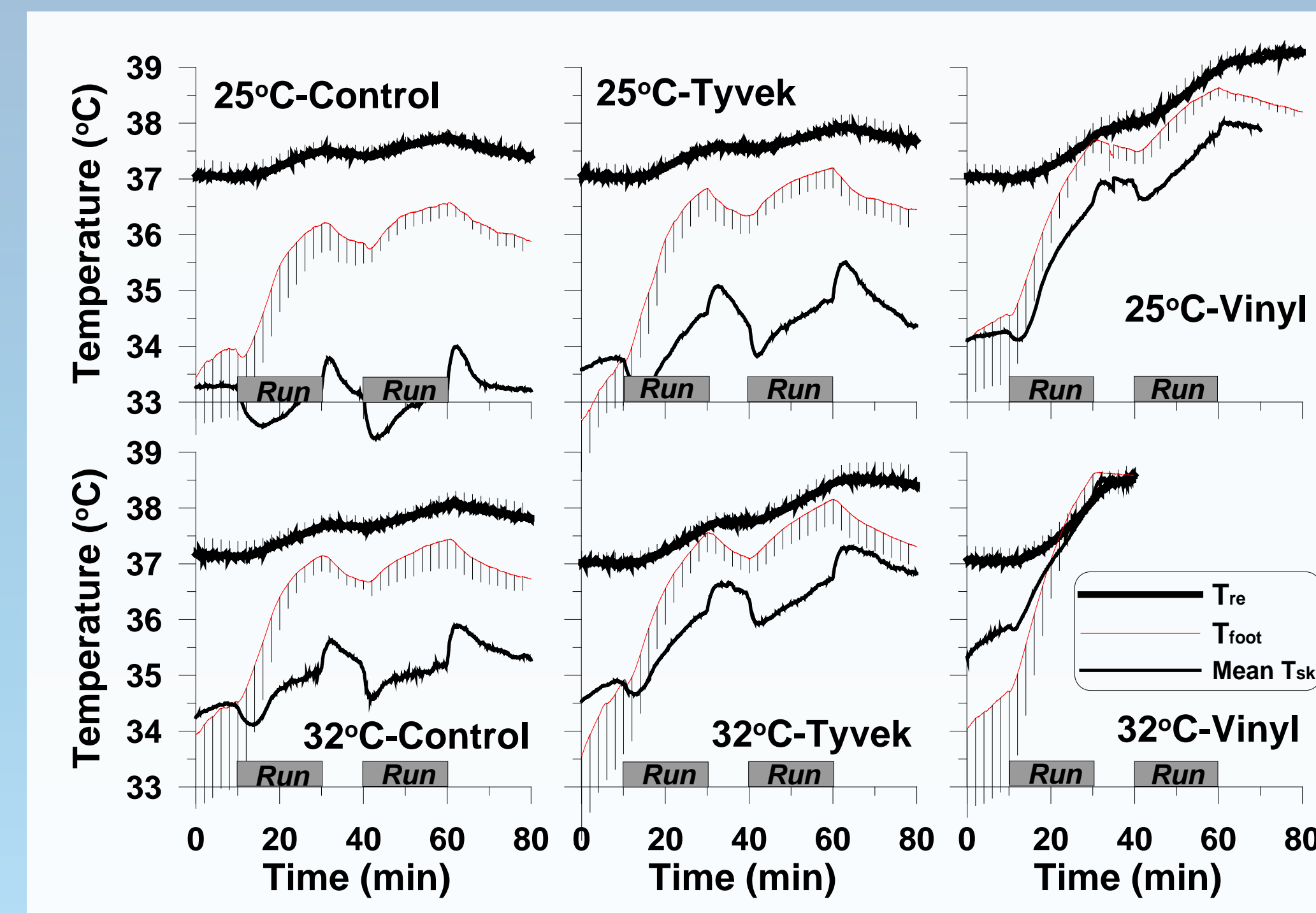


Fig. 1. [Series 1] Time course of rectal ( $T_{re}$ ), foot ( $T_{foot}$ ) and mean skin temperatures (mean  $T_{sk}$ ) during exercise.

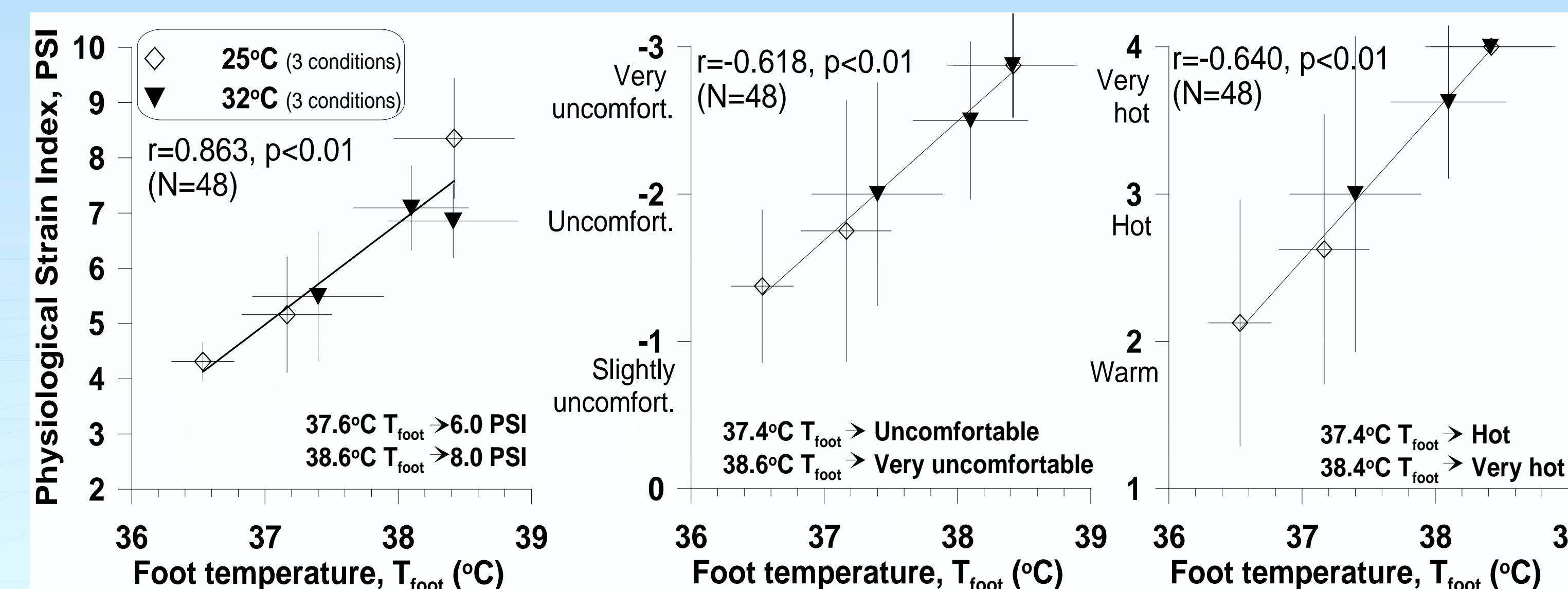


Fig. 2. [Series 1] Relationships of foot temperature with physiological strain index (Left), thermal comfort (middle), and thermal sensation (Right)

- **PSI:**  $T_{foot}$  of 37.6°C & 38.6°C → PSIs of 6.0 & 8.0, respectively
- **Thermal comfort:**  $T_{foot}$  of 37.4°C & 38.6°C → 'uncomfortable' & 'very uncomfortable'.
- **Thermal sensation:**  $T_{foot}$  of 37.4°C & 38.4°C → 'hot' & 'very hot'

■  $T_{foot}$  of 38.5°C was set as a '**Danger**' level. For an initial warning value (**Alarm**),  $T_{foot}$  of 38.0°C was tentatively determined from the half value between 'uncomfortable' and 'very uncomfortable', 'hot' and 'very hot'.

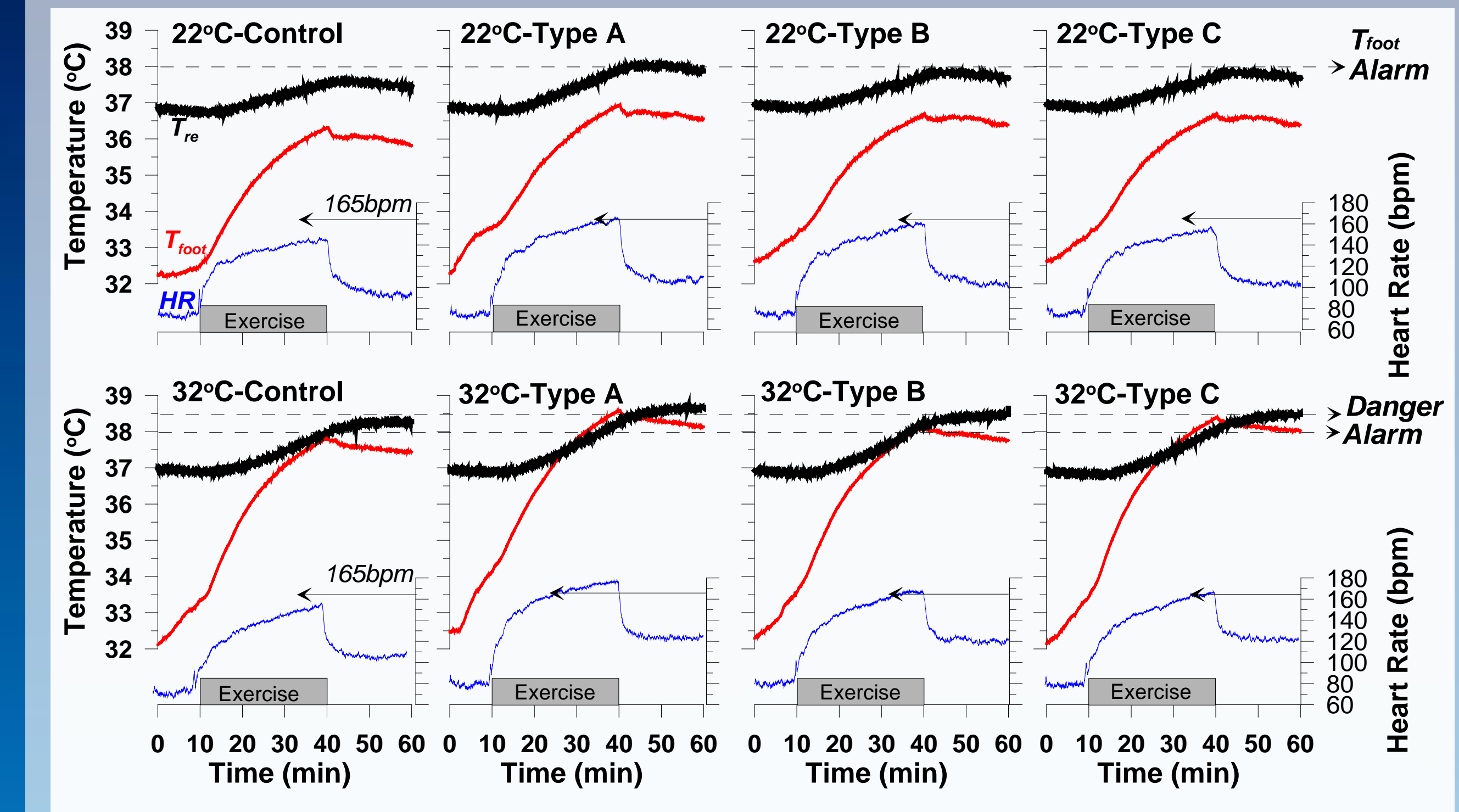


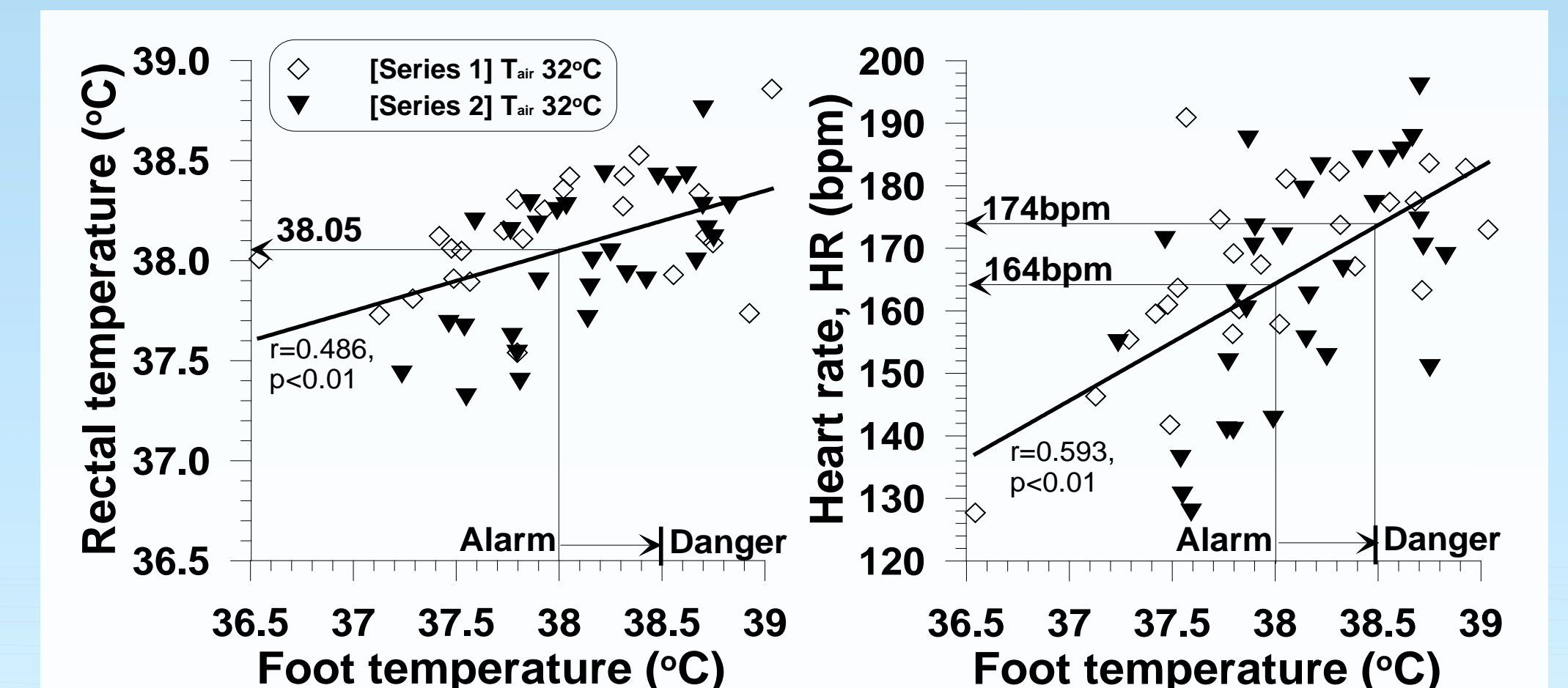
Fig.3. [Series 2] Alarm and Danger criteria on the time course of rectal ( $T_{re}$ ), foot ( $T_{foot}$ ) and heart rate during exercise wearing various SCBA.

■ The 'Alarm' and 'Danger' criteria in  $T_{foot}$  were then evaluated with new data set drawn from Series 2 (Fig. 3).

■ **Fig. 4 (Left):** The point of showing the identical value between  $T_{foot}$  and  $T_{re}$  was 38°C. This indicates that as  $T_{foot}$  rises up to 38°C,  $T_{re}$  then becomes greater than  $T_{re}$ , which means that temperature distribution between the core and shell is reversed at the  $T_{foot}$  of 38°C.

Fig. 4. [Series 1 & 2]

Relationships between foot temperature and rectal temperature (left); foot temperature and heart rate (right)



## Summary and Conclusions

- ◆  $T_{foot}$  of 38.0 and 38.5°C were determined as Alarm and Danger criteria, respectively.
- ◆ The Alarm level was set at the point that  $T_{foot}$  reached rectal temperature during exercise.
- ◆ The Danger level was determined at the moments that extreme subjective perceptions were given (very uncomfortable, very hot, and very hard).
- ◆ The Alarm and Danger criteria that derived from  $T_{foot}$  are valid for workers wearing full protective clothing (including protective boots) in hot environments, but cannot be applied to workers wearing light work wear in thermal neutral environments.

\*Correspondence: Joo-Young LEE (leex3140@design.kyushu-u.ac.jp)